Reprinted from
EOS
Vol. 57, No. 8, August 1976

Seismic Research Observatories: Upgrading the Worldwide Seismic Data Network

Jon Peterson and Nicholas A. Orsini

The World-Wide Standard Seismograph Network (WWSSN) was established in the 1960's to provide the data needed for fundamental research in seismology and global tectonics. It has served this purpose well over the past decade, contributing essential data during a period of accelerated progress in the understanding of earthquake and tectonic processes. The WWSSN will be the principal source of earthquake data for years to come, but some improvements are needed if the network is to keep pace with the data needs of the seismological community.

These needs have grown with advances in the development of theoretical models of the earth and its processes and with the capacity and versatility of digital computers and display devices. Today, most of the data used in seismological research, excluding oil exploration, continue to be recorded in analog form; the chief interfaces between modern computative machines and seismic data sources are the metric scale or a hand-guided digitizing device. There exists a fundamental gap between the available means of manipulating seismic data and the primitive form of most of the data.

Since the WWSSN was installed, there also have been important advances in instrument technology—long-period signal detection thresholds have been lowered through the refinement of seismic sensors, and recording techniques have been much improved through the application of digital electronics. The worldwide seismic data base could be enriched if these technologies were applied more extensively.

This was the objective of the Advanced Research Projects Agency (ARPA), in collaboration first with NOAA and then with the U.S. Geological Survey, when they initiated the Seismic Research Observatories (SRO) Project, a program to upgrade selected stations of the WWSSN. In an initial phase of this

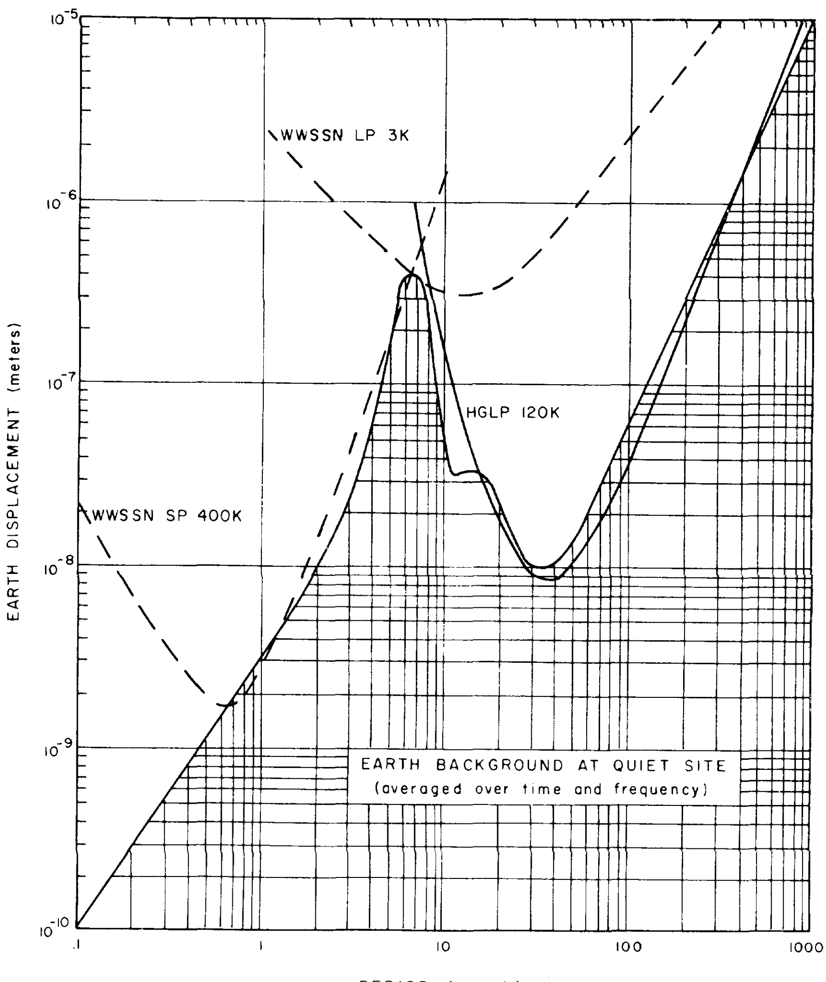


Fig. 1. Signal detection thresholds of the WWSSN LP and HGLP seismographs in relation to the approximate earth background level at a quiet site.

work an advanced digital-recording seismograph system was developed in which data are derived from a broad band borehole seismometer. Thirteen of these SRO systems will be installed at widely distributed locations. Together with improved long-period seismographs installed in recent years they will form an overlay network of about 25 digital-recording observatories to complement the WWSSN. Concurrently, a data management system is being developed with facilities for a central digital data bank. As in the case of the WWSSN the data collected from the new stations will be available to the international seismological community.

Background

Much of the instrument development work of the past decade has been concentrated on improving the quality of long-period data. For many years, short-period seismographs have been capable of resolving body wave signals that are not obscured by ambient earth background noise. Long-period seismographs, being less stable, are more sensitive to their operating environment, especially to small changes in temperature and pressure, and resolution is often limited by instrument-related noise. In fact, until quite recently the structure of earth noise in the long-period band was not well known. The long-period seismographs used in the WWSSN, for example, cannot resolve earth noise in the 20- to 40-s band, and long-period signals from many events are not detected, although they have energy well above background levels.

Using careful design and special installation techniques, *Pomeroy et al.* [1969] at the Lamont-Doherty Geological Observatory were able to increase the operating sensitivity of long-period seismographs by more than an order of magnitude for periods above 20 s in comparison to that of the WWSSN system. The Lamont group followed up this work by developing what is now called the high-gain long-period (HGLP) seismograph system. Digital recording was included to increase dynamic range. Eleven HGLP systems were installed as part of an ARPA-sponsored very long period experiment, and surface wave detection thresholds were lowered substantially (Figure 1).

Problems with long-period data recording were not all resolved at this point, however. Wind-generated noise often obscures data recorded on the HGLP system, particularly the horizontal components. Everyone has seen a field of grain waving in a breeze. It is difficult to imagine that the effect extends into subsurface rock, but it does. Studies by *McDonald et al.* [1971] and *Sorrells et al.* [1971] have shown how the earth responds to small atmospheric pressure cells that propagate along the surface at mean wind velocities (Figure 2). Horizontal component seismographs are most affected because of their sensitivity to the tilt component. Because this noise is produced by earth motion, it cannot be avoided by further improvement in the instruments or installation techniques. However, the earth motion is attenuated rapidly with depth, and *Sorrells* [1971] predicted that it would be negligible at a depth of 300 m for periods less than 30 s.

Attention then focused on the development of a borehole seismometer that could be used for long-period sensing. It was a challenging task, because the sensors had to be very small in comparison with conventional seismometers, with low self noise, yet sensitive enough to resolve angstrom level earth displacement in the long-period band. Several companies addressed this problem with support from government agencies. Miniaturization was achieved by using short-period seismometers as the sensing ele-

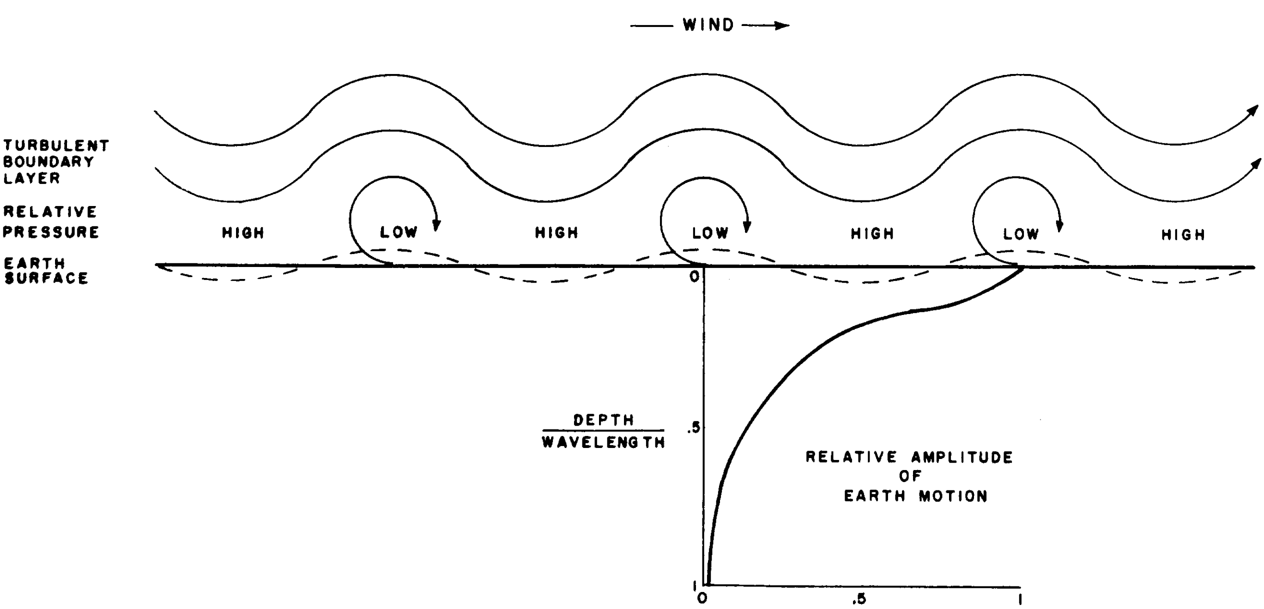


Fig. 2. Simplified schematic showing how the wind interacts with the earth surface. The effect is attenuated rapidly with depth. Data from *Sorrells* [1971].

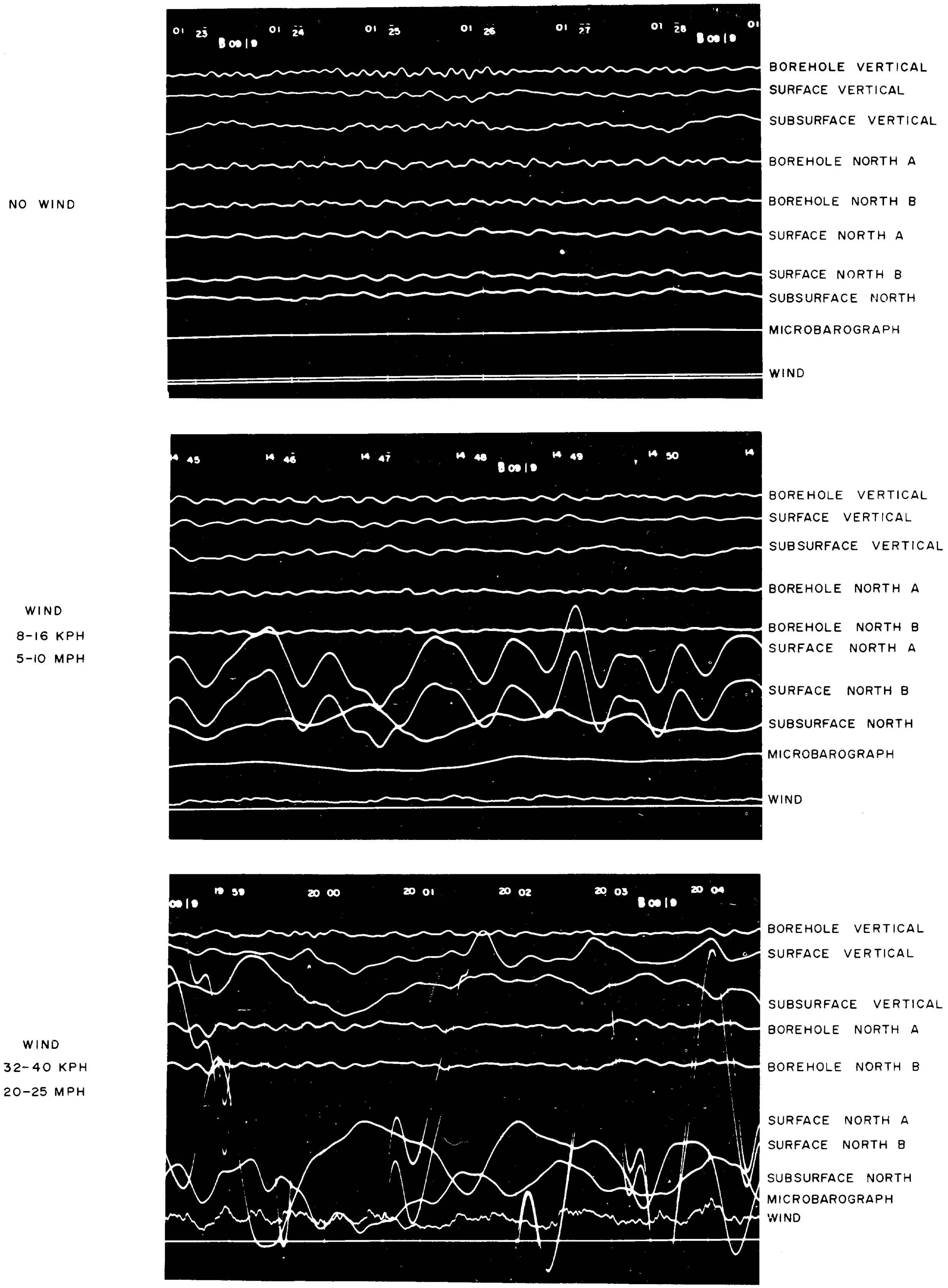


Fig. 3. Portions of film records showing data from a borehole seismometer operated at a depth of 100 m compared with data from conventional seismometers during various wind conditions. The data traces labeled 'subsurface' are derived from an HGLP system operated in an underground vault about 1/2 km from the borehole. The borehole horizontal sensors and 'surface' horizontal sensors were operated in parallel during these tests.

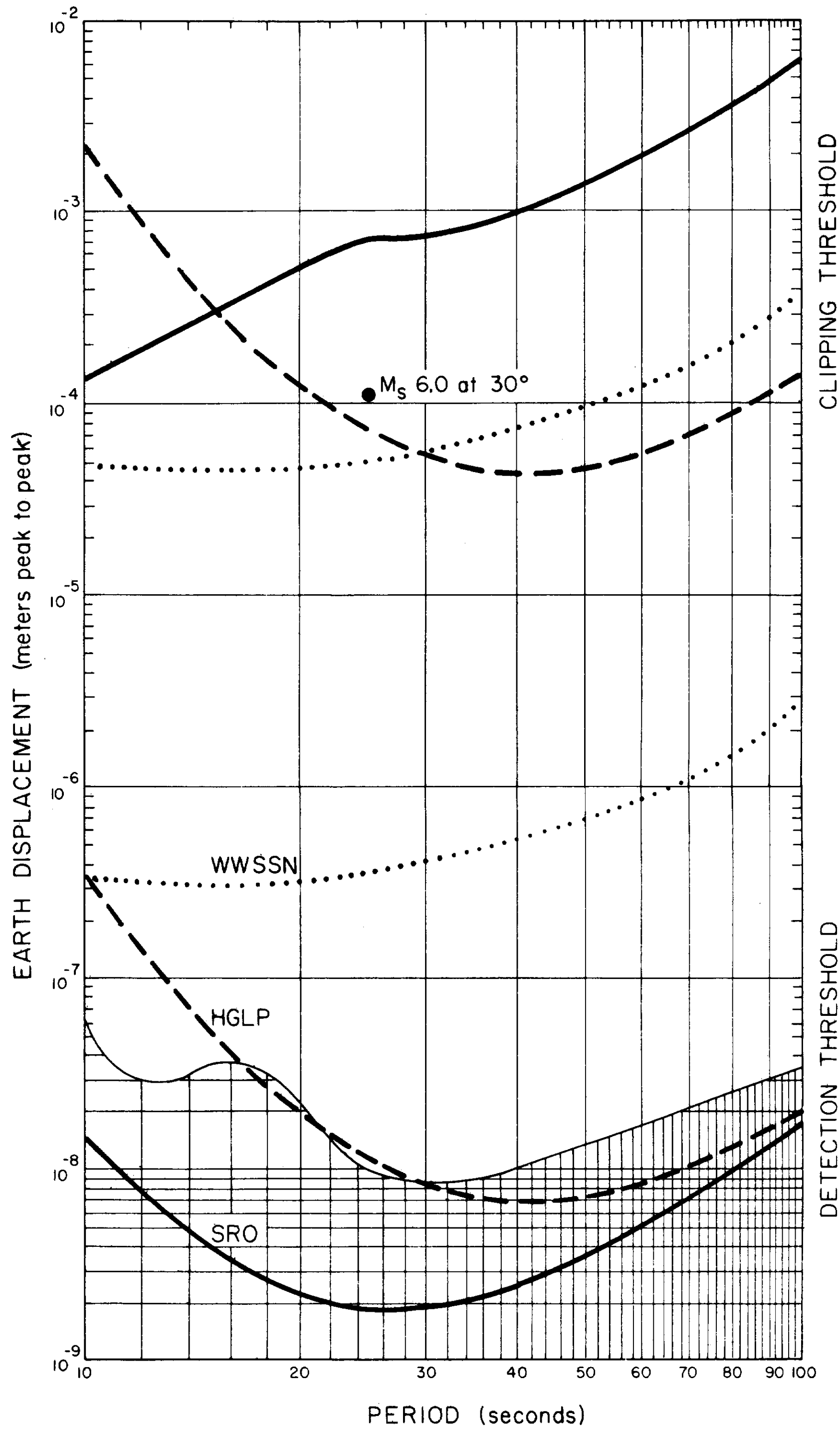


Fig. 4. Recording range of the SRO data system compared to the recording range of the WWSSN and HGLP systems in the long-period band.

ments, and instrument noise was reduced to acceptable levels by employing the very latest electronics technology and evacuating the sensor modules. The borehole seismometer developed by Teledyne-Geotech of Garland, Texas, was chosen for the SRO data system. This instrument was used to study wind noise reduction, and results satisfied expectations. Operated in a borehole at a depth of 100 m, the seismometer is unaffected by wind noise during periods in which the noise obliterates data from conventional seismometers operated near the surface (Figure 3). With this technique it is possible to operate consistently at sensitivities high enough to resolve both vertical and horizontal components of seismic signals that are not masked by normal earth background at the operating site.

Improvement of long-period sensing was one goal in the development of the SRO data system. Equally important is the capability to accommodate a large range of signal amplitudes. Most conventional seismographs, like the WWSSN instruments, record on drum recorders to produce the typical 24-hr seismogram. The recording range is quite limited, about 44 dB or a little over 2 orders of magnitude. This is not a very large slice of the earthquake magnitude scale. Digital recording may provide an excellent alternative. A digital recording system of the type used in the SRO project will provide 66 dB of resolution plus 60 dB of automatic gain control for a total of 126 dB of recording range—over 6 orders of magnitude (Figure 4).

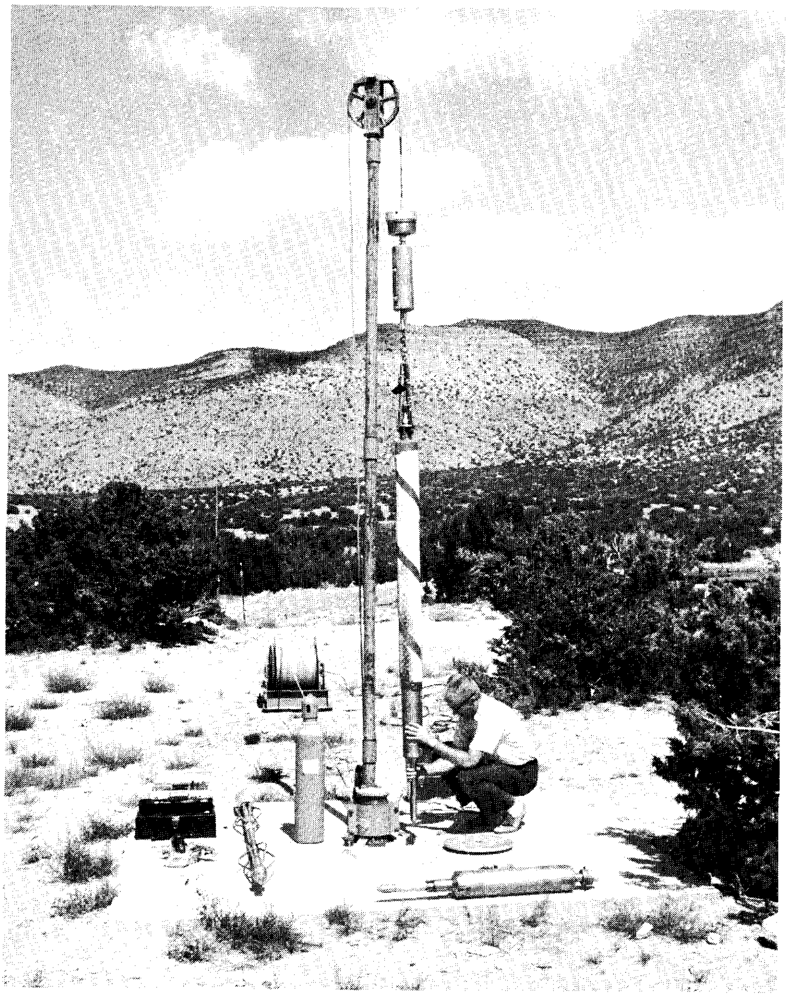
System Design

The SRO data system was created by combining the Teledyne-Geotech borehole seismometer and a modern digital data acquisition and recording system developed for this program by Unitech, Inc., of Austin, Texas.

The borehole seismometer (Figure 5) contains three orthogonally oriented sensors and their associated electronics. The seismometer is designed for installation in standard, 7-inch oil well casing and will operate with a vertical slant of as much as 4°. At most locations the seismometer will be installed at 100 m, as this depth appears to be a good trade off between noise reduction and cost. The signal output from each sensor is broad band, proportional to earth acceleration from 0.02 to 1 Hz. The broad band data are filtered in a wellhead terminal to produce long-period and short-period outputs, which are recorded separately. The wellhead terminal also contains the controls for leveling, unlocking, locking, and calibrating the sensors.

The SRO recording equipment is

Fig. 5. The borehole seismometer being prepared for installation. A hole lock is lowered and locked to the casing wall by using the installation tool shown in the lower right. The azimuthal orientation of the hole lock is determined by using a gyroscopic orientation device, shown on the left. The key at the base of the seismometer can then be aligned to produce north and east axes of the horizontal sensors. The seismometer package is filled with helium to reduce internal convections. The strain relief above the seismometer mechanically decouples the cable when the instrument is seated in the hole lock. The seismometer and accessories are raised and lowered by using the winch shown in the background.



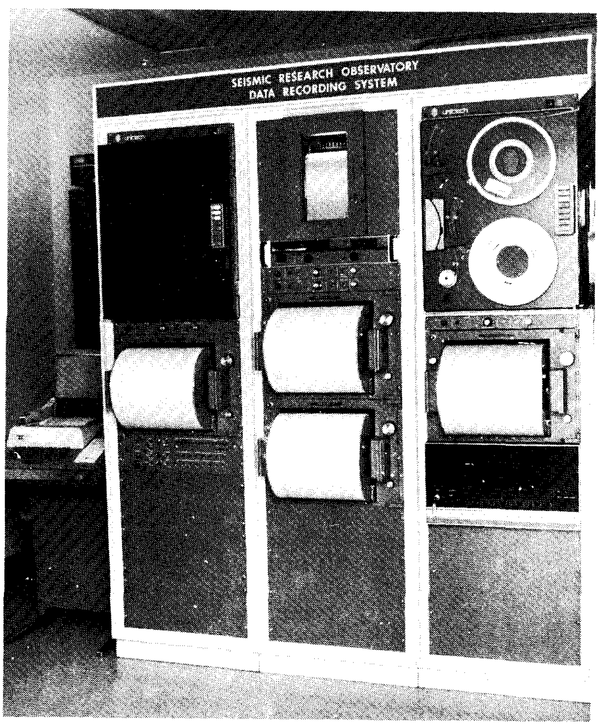


Fig. 6. Photograph showing the SRO data recording system. Left bay contains antialiasing filters, analog-to-digital converter, visual recorder, and a tape recorder. Middle bay contains two visual recorders, digital clock, and a strip chart recorder which the operator can use to verify the digital data. Right bay contains the computer, a visual recorder, and the second tape recorder. Teletypewriter is used to control system operations.

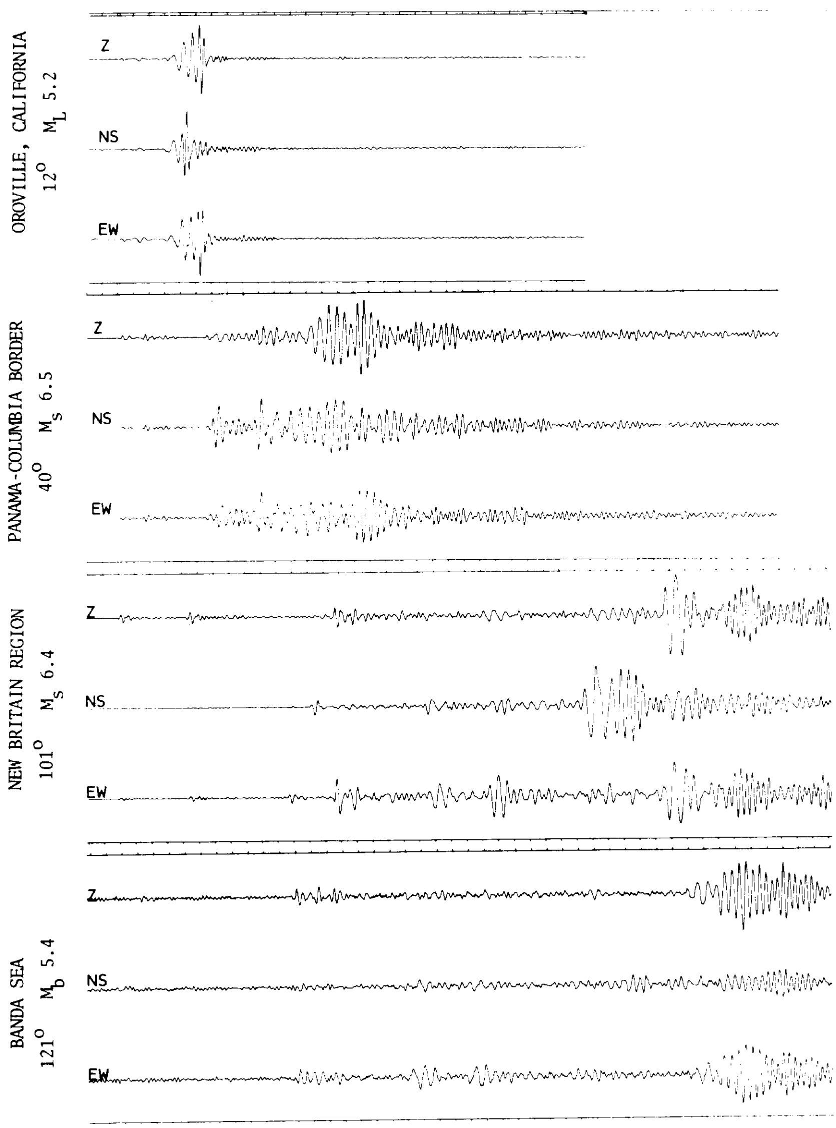


Fig. 7. Digital plots of some typical earthquakes recorded on the SRO at Albuquerque. Location, distance in degrees, and magnitude are shown on the left. Time marks are 1 min in length.

enclosed in a three-bay cabinet (Figure 6). The three long-period data channels and the vertical component short-period data channel are recorded on visual recorders to produce conventional seismograms. The same data are digitized, with long-period data sampled once each second, and short-period data, twenty times each second. All of the long-period data and events edited from the short-period data are then recorded on tape. Two magnetic tape recorders are furnished to insure uninterrupted digital recording. If a tape runs out (they last about 14 days) or if the on-line recorder fails, the data will be switched automatically to the standby recorder.

The station processor is a 16-bit minicomputer with 8 Kbyte of core memory and peripheral controllers. In addition to controlling the recording operations the station processor edits the short-period data so that only events and a short segment of data prior to the detected phase are recorded on tape. Continuous recording of short-period data would require frequent tape changes and result in excessive tape handling both at the station and in the data management system. The station operator communicates with the processor and controls the system through a teletypewriter. Operating software permits him to select recording modes, adjust gain levels, set event detection parameters, and calibrate the sensors. Event detection times are printed out automatically, as are any malfunctions or abnormal conditions sensed by the station processor. Diagnostic software is furnished to assist the operator in locating faults. A digital clock and radio receiver are furnished with the SRO system to provide station time; there is also a station power supply that provides 8 hr of backup should the line power be interrupted.

At some of the SRO stations, perhaps as many as half, the borehole facility will be located at some distance from the recording system, and it will be necessary to telemeter the data. The method used, either radio or wire, will depend on site conditions. Data will be first digitized, then transmitted in a format similar to Teletype code but at a higher clock rate. The communication link will be two-way so that the operator can transmit calibration commands to the sensors.

The preproduction SRO system was installed at the U.S. Geological Survey's Albuquerque Seismological Laboratory in August 1974. Plots of a few typical earthquakes recorded on this system are shown in Figure 7. Large-magnitude events that have overdriven both the WWSSN and HGLP systems at Albuquerque have recorded well on the SRO system. Analysts will appreciate the versatility of the digital data when they are plotted in analog form, as phases may be examined in detail by expanding the time base or increasing the magnification (Figure 8). And, of course, the digital data are especially well suited for studies that require computer processing.

The ASRO Data System

In a project closely associated with the SRO, some of the HGLP seismograph stations will be furnished with vertical component short-period seismometers and abbreviated versions of the SRO recording system. These modified HGLP stations (to be designated ASRO) will have functions, software, and digital data format identical to the SRO stations, the principal difference being that the conventional long-period seismometers at these stations will continue in use. There will be five ASRO stations.

Network Design

Sites for the SRO stations were selected jointly by ARPA and the U.S. Geological Survey on the basis of recommendations from the National Academy of Sciences/National Research Council Committee on Seismology. Most will be operated in conjunction with WWSSN stations, but there will be a few exceptions. The general geographical siting of the SRO stations was influenced by the location of existing HGLP stations, for together they will form an integrated global network of digital-recording observatories. More specific considerations were seismic noise levels as determined from existing data, geological setting, and the interest of prospective host organizations.

Of the 12 SRO stations that are to be located outside the continental United States, cooperative arrangements have been completed for ten. These will be located at or near Ankara, Turkey; Bogota, Colombia; Chiang Mai, Thailand (to replace an existing HGLP system); Guam; Mashhad, Iran; Mundaring, Australia; Nairobi, Kenya; Shillong, India; Taipei, Taiwan; and Wellington, New Zealand. The preproduction SRO system will remain at Albuquerque, New Mexico. Of the two systems currently unassigned, one will probably be located in Africa and one in western Asia. The existing and planned locations for the HGLP, ASRO, and SRO stations are plotted on the map shown in Figure 9.

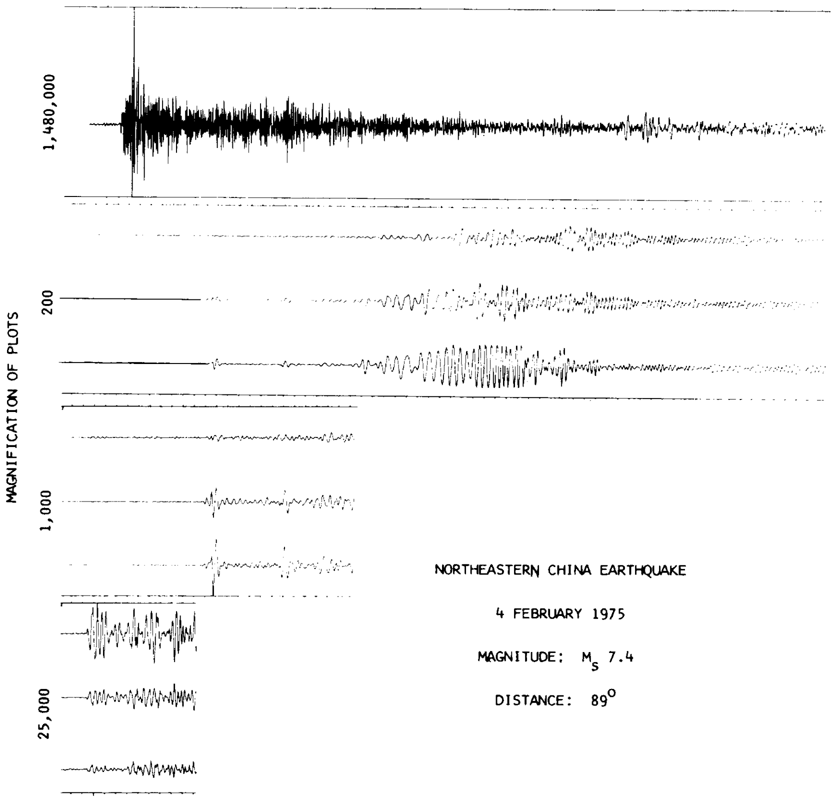


Fig. 8. Digital plots of a large-magnitude earthquake recorded on the SRO at Albuquerque. Top plot shows vertical short-period data. Second plot shows the three components of long-period data played back at low magnification to contain surface wave arrivals. Third plot was expanded in amplitude to show body phases, and bottom plot was further expanded in amplitude to show first arrival. Time marks are 1 min in length. All other long-period seismographs (WWSSN and HGLP) at Albuquerque were overdriven by this event.

Network Installation and Operation

The installation of an SRO system is preceded by several important activities. After arrangements are completed with the participating organization, representatives visit the station to determine what preparations are needed and to locate contractors to perform this work. Site preparation can be a difficult task. The borehole is the most important requirement, and it must be drilled to exacting specifications. At one location it was necessary for the subcontractor to dismantle his drilling rig and carry it piece by piece up a mountain to the borehole site. Many of the host organizations are sharing in the costs of site preparation.

Training is essential. Personnel from each participating station are given an intensive 5-week course of instruction in the operation and maintenance of the SRO system. Classes are held at the U.S. Geological Survey's Albuquerque Seismological Laboratory, using the preproduction SRO system as the principal training aid.

Equipment is installed by a two-man team aided by station personnel. Installation and checkout can be completed in about 4 weeks.

Once the equipment is installed, title to it passes to the participating organization, usually either a university or a government agency. As in the case of the WWSSN program, station personnel operate and maintain the equipment, but the U.S. Geological Survey supports the network stations with technical assistance, supplies, and on-site maintenance when these are needed.

Data Management

The principal purpose of the SRO project is to provide data for research; thus its success depends on making the data accessible to

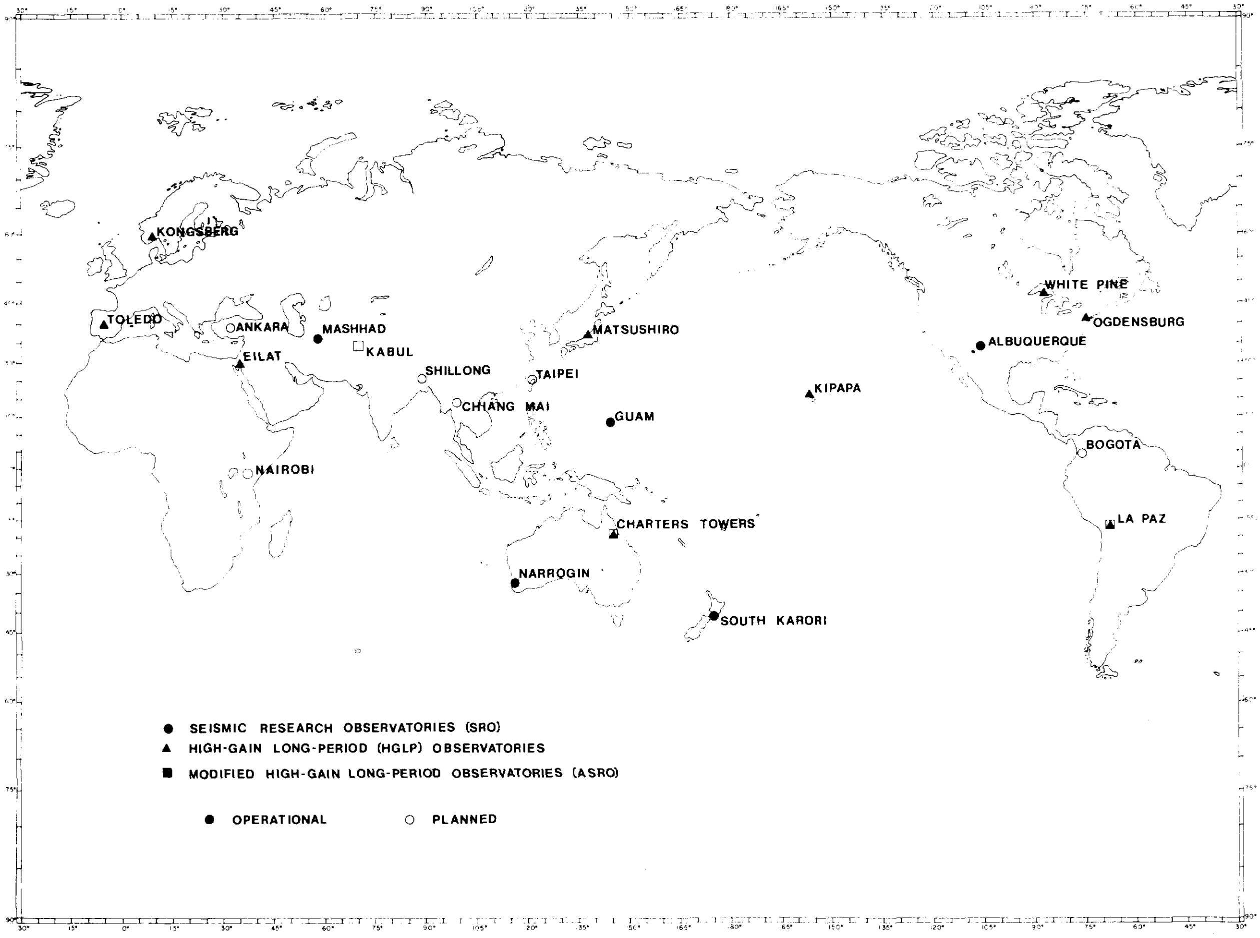


Fig. 9. Map showing current and planned locations for the HGLP, ASRO, and SRO stations.

research scientists. A data management system is being established to process, store, and disseminate data collected from the digital-recording networks and seismic arrays. Digital tapes and seismograms generated at the network stations will be mailed at biweekly intervals to the Albuquerque Seismological Laboratory, where they will be reviewed for quality and entered into the data system. Seismograms, and possibly plots of important earthquakes, will be sent to the NOAA/Environmental Data Service for microfilming, and copies will be distributed to subscribers in the same manner as for the WWSSN seismograms. The reproduction of seismograms or film chips from the digital tapes is being considered as an alternative to the collection and processing of station seismograms. The reproductions are superior to the conventional seismograms in several respects: they have greater dynamic range and can be plotted at any magnification.

Facilities for handling the digital data are being developed by the ARPA. They will be managed by the Vela Seismological Center through its Seismic Data Analysis Center located in Alexandria, Virginia. Seismic data and related information will be stored initially in a mass data storage facility operated by the Computer Corporation of America. The Seismic Data Analysis Center will also be collecting data from seismic arrays located in Montana, Alaska, Norway, Korea, and Iran. The array data will be analyzed by automated event detection and event association processors to produce a daily summary that will list events and their associated parameters. The event summary will be updated as additional information is derived from other sources, principally from the U.S. Geological Survey's National Earthquake Information Service. The event summaries, associated wave forms, and raw array data will be placed in the mass data store to be augmented later by SRO network data as tapes are received from the stations. Research seismologists are encouraged to make use of the SRO data. They are available through the Seismic Data Analysis Center, Teledyne-Geotech (P.O. Box 334, Alexandria, Virginia 22313).

Applications of the SRO Data

The SRO network will provide a high-quality digital data resource for those problems of seismology that are best addressed through a worldwide distribution of sample points. These problems include source mechanism research, global seismicity distribution studies, and gross and regional earth structure resolution.

The short-period spectrum (0.3–3 Hz) is probably less well understood than any other commonly observed at teleseismic distances. Surely this band contains detailed information concerning the seismic source and the fine structure of the earth; but only in special cases and regions where an array of short-period seismometers has been deployed with special digital recording equipment has this information been fully exploited. Commonly, both in routine analysis and in special research studies, only two measurements are derived from a typical short-period record—magnitude and arrival time. The form of the SRO short-period data will allow filtering operations, spectral computation, and quantitative correlation with theoretical wave forms to be made with relative ease. This capability should help spur research into the understanding of the short-period seismic field of the earth.

Another area in which potential exists for the SRO data is in the routine estimation of source parameters. Since the introduction of the magnitude scale some 40 yr ago, short- and long-period magnitudes continue to be the only source parameters (other than location) to be routinely published in bulletins. Within that time, however, source concepts such as moment, stress drop, relaxation volume, dislocation, fault plane orientation, and rupture velocity have all been set forth as important characteristics of the source estimatable only through spectral or wave form correlation with appropriate models. The SRO data will make it technically feasible to estimate some or all of these parameters routinely. This will lead to a better understanding of the state of stress in the earth and the mechanisms through which the stress is released.

Acknowledgments

The authors would like to express their appreciation to the directors and staffs of the following organizations that are participating in the SRO project: Chinese Earthquake Research Center, Taipei, Taiwan; Department of Mines and Geology, Ministry of Natural Resources, Nairobi, Kenya; Guam Observatory, U.S. Geological Survey, Guam, Marianas Islands; Institute of Geophysics, University of Tehran, Tehran, Iran; Instituto Geofisico de Los Andes Colombianos, Universidad Javeriana, Bogota, Colombia; Meteorological Department, Bangkok, Thailand; Middle East Technical University, Ankara, Turkey; Mundaring Observatory, Bureau of Mineral Resources, Mundaring, Australia; Seismology Observatory, Department of Scientific and Industrial Research, Wellington, New Zealand; and the Seismology Division, Indian Meteorological Department, New Delhi, India.

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Jon Peterson heads the U.S. Geological Survey's Albuquerque Seismological Laboratory, which serves as the headquarters for the worldwide seismic data networks described in this article. He graduated from the University of Minnesota in 1958. Since 1961 his principal activities have been in the field of seismic instrumentation and in the establishment and management of the seismograph networks.

Nicholas A. Orsini is a program manager with the ARPA. A lieutenant colonel in the USAF, he has devoted much of his career to working on the Vela project. In addition to the SRO project, he is currently managing projects to install a seven-element long-period borehole array in Iran and to upgrade selected HGLP stations. He obtained his B.S. in geology from Colgate University and did graduate work in seismology at St. Louis University.